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RESEARCH MEMORANDUM

PERFORMANCE INVESTIGATION OF CAN-TYPE COMBUSTOR FROM BRITISH TURBOJET ENGINE AND COMPARISON OF THIS COMBUSTOR WITH CAN-TYPE COMBUSTOR FROM U.S. TURBOJET ENGINE

By William P. Cook and Richard G. Koch

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUM

PERFORMANCE INVESTIGATION OF CAN-TYPE COMBUSTOR FROM BRITISH TURBOJET ENGINE AND COMPARISON OF THIS COMBUSTOR WITH CAN-TYPE COMBUSTOR FROM U.S. TURBOJET ENGINE

By William P. Cook and Richard G. Koch

SUMMARY

An investigation was made of the performance of a single can-type combustor from a British gas-turbine engine over a wide range of operating conditions, some of which simulated operation in flight. Information was obtained concerning the altitude operating limits imposed on the design engine by the combustor, the combustion efficiency, the total-pressure loss through the combustor, the pressure distribution inside the combustor, and the temperature distribution at the combustor outlet. A comparison was made of the combustion efficiencies of the British combustor and of a typical U.S. can-type combustor at the same operating conditions. A comparison of the pressure losses in the two combustors was also made.

The combustion efficiencies of the British combustor operating at simulated-altitude flight conditions ranged from 55.4 percent at flight conditions near the operating limits to 98.6 percent at the low-altitude - high-speed conditions investigated. The efficiency, in general, increased with increase in engine speed and with decrease in altitude. The engine for which the British combustor was designed has much lower area specific air flows than the engine for which the U.S. combustor was designed. As a result of this design, at full engine speed and at comparable altitudes, the British combustor with the British engine would operate at higher efficiencies than would the U.S. combustor with the U.S. engine.

The ratio of the total-pressure loss through the British combustor to the reference dynamic pressure (computed from air mass flow, combustor-inlet density, and maximum combustor cross-sectional area) was 82 for isothermal flow, which is about eight times as large as the corresponding value for the U.S. combustor.

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The exhaust-gas temperature-distribution pattern found with the British combustor generally showed an increase in temperature from the short radius side (blade root) to the long radius side (blade tip) of the outlet. As the average exhaust-gas temperature increased from 500° to 1500° F, the mean deviation increased from 24° to 117° F with the British combustor and from 71° to 138° F with the U.S. combustor. At the same time the maximum deviation increased from 90° to 274° F with the British combustor and from 137° to 310° F with the U.S. combustor.

INTRODUCTION

As part of a general program of research on combustors for gas-turbine engines at the NACA Lewis laboratory, the effect of combustor-inlet-air conditions on combustion efficiency and temperature-rise limits has been investigated (reference 1). The effect on combustor performance of the arrangement of the air passages in the combustor liner has also been studied with various combustors (for example, reference 2). Different fuels and fuel-injection systems have also been investigated to determine their effects on combustor performance (reference 3). Other work in this same general program has been conducted to determine the performance characteristics of various types of combustor (references 4 and 5), and a comparison has been made of the performance of different combustor types (reference 6).

The present investigation is a further contribution to the general subject of the effect of the design of the combustor on performance. A single British can-type combustor having certain unique design features was investigated during a 4-month period ending in February 1949. The combustor was connected to the laboratory air-supply and exhaust systems and was investigated over a wide range of operating conditions, some of which simulated operation in flight.

The combustion efficiencies and the altitude operating limits were determined at a number of simulated engine speeds and altitudes. Combustion efficiences were also measured at various air flows and values of combustor temperature rise at two fixed inlet-air conditions specified as standard for combustor investigations. Investigations were also made of the pressure losses through the combustor, the pressure distribution inside the combustor, and the temperature distribution at the combustor outlet.

These data were then used to compare the performance of the British combustor with similar performance data obtained in an earlier investigation with a U.S. can-type combustor. This comparison was made to determine the differences in performance resulting from the differences in combustor design.

APPARATUS AND INSTRUMENTATION

British Combustor

A simplified sketch of the British can-type combustor used in this investigation is shown in figure 1(a). The maximum cross-sectional area of the combustor housing is $108\frac{1}{2}$ square inches and the length of the combustor liner is $24\frac{1}{2}$ inches. Fuel is injected by a single pressure-atomizing, hollow-cone spray nozzle. The first 20 percent of the total air flow is admitted over a length of $4\frac{1}{2}$ inches of the liner, assuming that the flow is distributed in direct accordance with the air-passage areas. The first 4.3 percent of the total air flow passes through swirl vanes, which surround the fuel nozzle. The combustion zone begins at a point that is $4\frac{3}{4}$ inches from the upstream end of the combustor liner; the space upstream of the combustion zone is occupied by flow dividers and flow-distributing devices.

U.S. Combustor

A sketch of the U.S. can-type combustor with which comparisons are made is shown in figure 1(b). The maximum cross-sectional area of the combustor housing is $70\frac{1}{5}$ square inches and the length of the combustor liner is $26\frac{3}{4}$ inches. Fuel is injected by a nozzle of the same general type as that used in the British combustor. The first 20 percent of the total air flow is admitted over a length of $7\frac{19}{32}$ inches of the liner, again with the assumption that the flow is distributed in direct accordance with the air-passage areas.

Experimental Setup

A diagram of the setup for investigating the performance of the British combustor is shown in figure 2. The combustor was connected to the laboratory air-supply and exhaust systems, and air quantities and combustor pressures were regulated by valves located upstream and downstream of the combustor. The exhaust gases were cooled by means of water sprays in the exhaust ducting.

The combustor-inlet-air temperature was regulated by burning a portion of the air with gasoline in a preheater and then uniformly mixing these gases with the remainder of the air upstream of the combustor. The quantity of air passing through the preheater was regulated by valves so as to maintain efficient combustion in the preheater.

The adapter sections at the inlet and the outlet of the combustor were production parts obtained from the manufacturer. The combustor-inlet adapter was fitted onto a 12-inch-diameter air-supply pipe, which served as a plenum chamber and as an inlet instrument section (station A, fig. 2). The instrument section at the combustor outlet (stations B and C, fig. 2) was fabricated to give a cross section conforming to the dimensions and the contours of the combustor discharge nozzle in the engine and was made long enough to carry the necessary instrumentation.

Instrumentation

Air flow was metered by a thin-plate orifice installed and calibrated according to A.S.M.E. specifications. Fuel flows to the combustor and the preheater were metered by calibrated rotameters. The combustor-inlet-air temperature and total pressure were measured at station A (fig. 2) by a pair of two-junction iron-constantan thermocouple rakes (fig. 3(a)) and a pair of three-tube total-pressure rakes (fig. 3(b)).

Temperatures and total pressures at the combustor outlet were measured by six five-junction chromel-alumel thermocouple rakes (fig. 3(c)) at station B (fig. 2) and by six five-tube total-pressure rakes (fig. 3(d)) at station C (fig. 2). The outlet thermocouple junctions and pressure tubes were located at centers of equal areas in the duct and provided one point of temperature measurement and one point of pressure measurement each 1.08 square inches of duct cross-sectional area.

Pressures inside the combustor were measured by three pairs of wall static-pressure taps located at the positions indicated in figure 2. Each pair of taps consisted of one tap to measure the pressure at the inside wall of the combustor housing and one tap to measure the pressure at the inside wall of the liner.

Pressures were recorded by photographing manometers; temperatures were recorded by a self-balancing recording potentiometer and were checked at intervals with an indicating potentiometer.

PROCEDURE

Experimental

Combustor performance investigations were conducted at conditions simulating a flight Mach number of 0 in the engine for which the combustor was designed at altitudes ranging from sea level to 65,000 feet (or at as high a simulated altitude as the laboratory services permitted) and at engine speeds from 40 to 100 percent of rated speed. The fuel used was AN-F-32 because it corresponds closely to the design fuel for this engine.

The combustor-inlet-air conditions and the required combustor-outlet temperature for each altitude and engine speed were taken from early engine performance data obtained at the NACA Lewis laboratory and are shown by the solid curves in figure 4. Further analysis of the experimental data and further experiments with the engine in an investigation independent of the one reported herein revealed errors in these engine performance data. The correct data are shown by the dashed curves in figure 4. The errors were not discovered until the investigation reported herein was complete and therefore the data from the solid curves were used.

In order to determine the altitude operating limits and the combustion efficiencies at various simulated flight conditions, the air flow, the inlet-air pressure, and the inlet-air temperature were adjusted to the values required to simulate a particular flight condition (fig. 4), and the fuel flow was adjusted to obtain the combustor-outlet temperature required for each simulated flight condition. The ignition system was used only for igniting the fuel and as soon as flame propagation occurred in the combustor the ignition system was turned off. The outlet-gas temperature was considered to be the arithmetical average of the 30 thermocouple readings immediately downstream of the combustor-outlet nozzle. If the required outlet temperature could be attained, the simulated flight conditions were recorded as being in the operable range of the engine and the combustion efficiency was determined. If the required outlet-gas temperature could not be attained, the flight conditions were recorded as being in the inoperable range of the engine.

Combustion efficiencies were measured at various values of air flow and of combustor temperature rise at each of two combinations of inlet-air temperature and pressure (620° R and 15 lb/sq in. absolute; and 710° R and 25 lb/sq in. absolute), which are usually used in combustor investigations.

Data were also recorded on pressure losses across the combustor, pressure distribution inside the combustor, and combustor-outlet-gas temperature profiles.

Calculations

The combustion efficiency, as used herein, is arbitrarily defined as the ratio of the measured temperature rise through the combustor to the temperature rise theoretically possible with the particular fuel and fuel-air ratio used. Thermocouple indications were taken as true values of total temperature with no corrections for radiation or stagnation effects. In order to record combustor pressure losses on a dimensionless basis, the ratio of the pressure losses to a reference dynamic pressure was used. The reference dynamic pressure was computed for each experimental condition using the air flow through the combustor, the density at the combustor inlet, and the maximum cross-sectional area of the combustor housing.

RESULTS AND DISCUSSION

Altitude Operating Limits

The altitude operating limits were determined by interpolating between simulated flight conditions where the required temperature rise was obtained and conditions were the required temperature rise was unobtainable. The fairing of the curve between the data points was based on observations of the performance of the combustor; the curve was drawn very close to those data points where the maximum-obtainable combustor-temperature rise was very close to the value required for engine operation. The altitude limits at speeds less than 70 percent of normal rated could not be determined because limitations in laboratory facilities made it impossible to obtain the low inlet-air temperatures required to simulate the higher altitudes at these low engine speeds. Differences in altitude operating limits less than 2000 feet are difficult to determine experimentally because of the erratic performance of the combustor at conditions near the altitude limit. It is again noted that the combustor operating conditions used for the British combustor were revised subsequent to this investigation.

The altitude operating limits of the British combustor at various simulated engine speeds (based on the engine conditions in fig. 4) are shown by the dashed curve in figure 5. The operating limits are approximately 64,000 and 53,000 feet at rated engine speed and at 70 percent of rated engine speed, respectively.

The altitude operating limits obtained with the British combustor compare with data obtained in a similar earlier investigation with the U.S. combustor (reference 4) as follows: At rated speed for both engines, the British combustor has operating limits approximately 10,000 feet above those of the U.S. combustor; at engine speeds below 90 percent of rated speed, however, the operating limits are about 3000 feet higher for the U.S. combustor. This comparison does not afford a true evaluation of relative combustor performance because it compares the performance in two different engines and hence at different operating conditions.

Combustion Efficiencies

The combustion efficiencies obtained at various simulated flight conditions with the British combustor are indicated beside the data points in figure 5. From interpolation between these data points, the constant-efficiency curves were drawn on figure 5. The efficiencies range from 55.4 percent at flight conditions near the operating limits to 98.6 percent at the low-altitude - high-speed conditions investigated. In general, the efficiency increased with increase in engine speed and with decrease in altitude.

Combustion efficiencies of the British combustor at various area specific air flows (defined herein as air flow in lb/(sec)(sq ft) at the maximum combustor cross-sectional area) and values of temperature rise are shown in figure 6 for an inlet-air temperature of 620° R and an inlet-air pressure of 15 pounds per square inch absolute. Similar data are shown in figure 7 for an inlet-air temperature of 710° R and an inlet-air pressure of 25 pounds per square inch absolute. From interpolation between the data points, constant-efficiency curves are presented in both figures. Figures 6 and 7 show that combustion efficiency for most conditions decreases with increase in the area specific air flow. For a given value of the area specific air flow, an optimum value of combustor temperature rise exists, above and below which combustion efficiency decreases. Constant-efficiency curves for the British combustor (fig. 6) are compared in figure 8 with constant-efficiency curves for the U.S. combustor. These curves were obtained at the same operating conditions. For a given value of the coordinates of figure 8, the combustor operating conditions, (inlet-air temperature, inlet-air pressure, temperature rise, and area specific air flow) are the same for both combustors. Figure 8 shows that the U.S. combustor gives higher combustion efficiencies than the British combustor at high area specific air flows. The engine for which the British combustor was designed has much lower area specific air flows than the engine for which the U.S. combustor was designed. As a result of this design, at full engine speed and at comparable altitudes, the British combustor with the British engine would operate at higher efficiencies than would the U.S. combustor with the U.S. engine.

Pressure Losses and Distribution

The data for the total-pressure loss from the inlet to the outlet of the British combustor are presented in figure 9. The ratio of the total-pressure loss to the reference dynamic pressure $\Delta P/q_R$ is plotted as a function of the ratio of the inlet-air density to the exhaust-gas density ρ_1/ρ_2 and a linear correlation is obtained. For isothermal flow through the combustor $\Delta P/q_R$ is about 82; for combustion resulting in a density ratio of 2.5, $\Delta P/q_R$ is about 102. The values of $\Delta P/q_R$ for the British combustor are also compared with similar data for the U.S. combustor in figure 9. The isothermal $\Delta P/q_R$ for the British combustor is about eight times the value for the U.S. combustor.

Because the British combustor was designed for an engine that provided a lower air flow per unit combustor cross section than the U.S. combustor, the ratio of the ΔP in the British combustor to the ΔP in the U.S. combustor is less than the ratio of $\Delta P/q_R$ for the British combustor to the $\Delta P/q_R$ for the U.S. combustor. At conditions simulating operation of the two combustors in their respective engines at rated speed and an altitude of 40,000 feet, the total-pressure loss through the British combustor is 5.45 inches of mercury and the total-pressure loss through the U.S. combustor is 1.28 inches of mercury.

The static-pressure differential between the inside wall of the housing and the inside wall of the liner is shown in figure 10 at three different locations along the length of the British combustor. (See fig. 2.) Values of $\Delta P/q_R$ are plotted as a function of ρ_1/ρ_2. Figure 10 shows that at an isothermal condition the values of $\Delta P/q_R$ are 17.8, 18.8, and 28.5 at the upstream, center, and downstream locations in the combustor, respectively. At a density ratio of 2.5, the $\Delta P/q_R$ values are 19.5, 23.5, and 46.5 at the locations previously mentioned. These data indicate that the air flowing into the combustion zone through the holes in the combustor liner is not distributed along the length of the combustion zone in direct accordance with the distribution of the air-passage area. More air per unit hole area will flow through the holes at the downstream end than will flow through the holes at the upstream end of the combustor. Because the pressure loss across the liner increases with increase in density ratio across the combustor more at the downstream end than at the upstream end, a smaller fraction of the total air flows into the upstream end of the combustion zone as the fuel flow (and hence the density ratio across the combustor) is increased.

The static pressures at the inside walls of the housing and the liner of the British combustor are presented in figure 11 for two air flows. These pressures are for isothermal air flows of 3.0 and 3.5 pounds per second and for an inlet-air total pressure of 29.5 inches of mercury absolute and inlet-air temperature of approximately 80° F. Figure 11 shows that from the upstream end to the downstream end of the combustor the static pressure along the inside wall of the housing increases and the static pressure along the inside wall of the liner slightly decreases. For example, with an air flow of 3.5 pounds per second, the static pressure in the housing increased from 22.63 to 23.62 inches of mercury, whereas in the liner the static pressure decreased from 21.22 to 21.00 inches of mercury.

Exhaust-Gas Temperature Distribution

The temperature-distribution patterns at the outlet of the British combustor are shown in figure 12. These patterns were obtained in investigations at 70 and 100 percent of rated engine speed at (1) the lowest altitude investigated and (2) the highest altitude investigated below the altitude limit. These patterns generally show an increase in temperature from the short radius side to the long radius side of the instrument section. On the engine, this increase would correspond to an increase in temperature from the roots to the tips of the turbine blades and such a temperature distribution is generally desirable because it is most favorable for long turbine operating life. Somewhat similar temperature patterns for the U.S. combustor (references 4 and 7) indicated that the highest temperature almost invariably existed in the center of the combustor outlet.

The maximum and mean deviation from the average outlet temperature found at the lowest altitude investigated and at the highest altitude below the altitude limit are shown in figure 13. This figure indicates that as the average outlet temperature increases from 500° to 1500° F, the mean deviation increased from 24° to 117° F for the British combustor and from 71° to 138° F for the U.S. combustor. At the same time the maximum deviation increased from 90° to 274° F for the British combustor and from 137° to 310° F for the U.S. combustor.

SUMMARY OF RESULTS

An investigation of the performance of a British can-type combustor at various operating conditions, some of which simulated flight conditions, gave the following results:

1. The combustion efficiencies of the British combustor operating at simulated-altitude flight conditions ranged from 55.4 percent at flight conditions near the altitude limits to 98.6 percent at the low-altitude - high-speed conditions investigated. The efficiency, in general, increased with increase in engine speed and with decrease in altitude.

2. At high air flows, the combustion efficiency of the U.S. combustor used for comparison was higher than that of the British combustor for the same combustor operating conditions of inlet-air pressure, inlet-air temperature, temperature rise, and area specific air flow. The engine for which the British combustor was designed has much lower area specific air flows than the engine for which the U.S. combustor was designed. As a result of this design, at full engine speed and at comparable altitudes, the British combustor with the British engine would operate at higher efficiencies than would the U.S. combustor with the U.S. engine.

3. The ratio of the total-pressure loss through the British combustor to the reference dynamic pressure (computed from air mass flow, combustor-inlet density, and maximum combustor cross-sectional area) was 82 for isothermal flow, which is approximately eight times as high as for the U.S. combustor.

4. The temperature-distribution patterns at the British combustor outlet generally showed an increase in temperature from the short radius side (blade root) to the long radius side (blade tip) of the outlet. As the average outlet temperature was increased from 500° to 1500° F, the mean deviation increased from 24° to 117° F for the British combustor and from 71° to 138° F for the U.S. combustor. At the same time the maximum deviation increased from 90° to 274° F for the British combustor and from 137° to 310° F for the U.S. combustor.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

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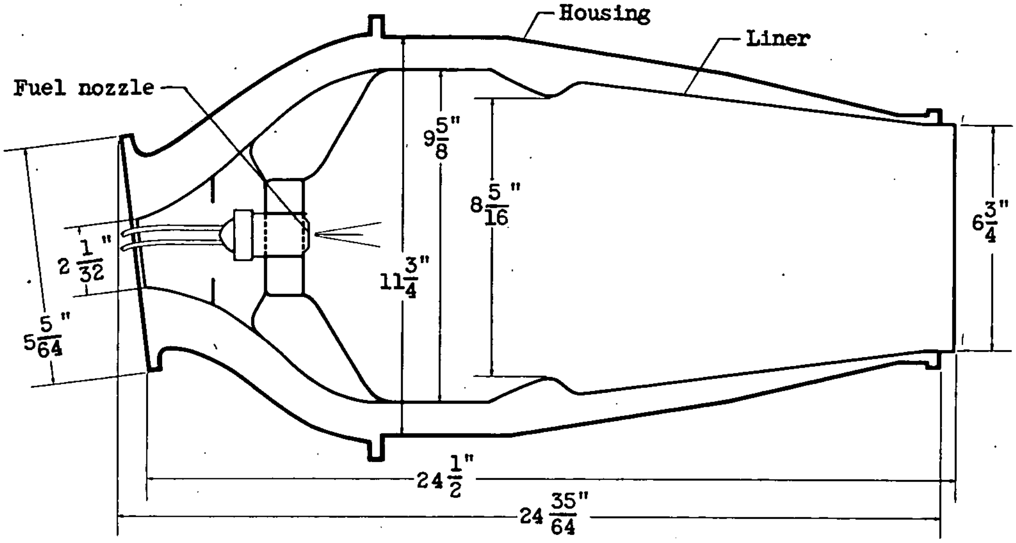
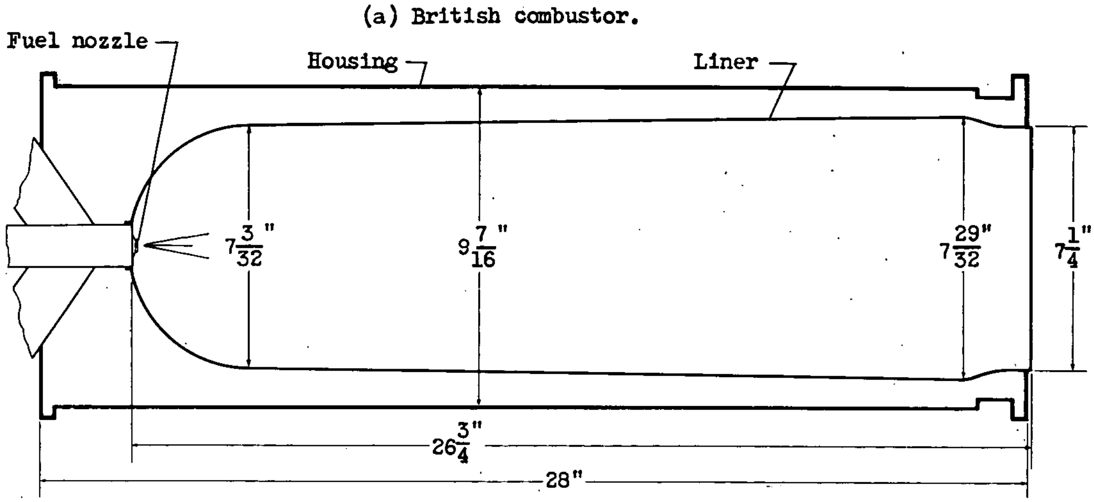


(a) British combustor.



(b) U.S. combustor.

Figure 1. - Sketches of British and U.S. can-type combustors.

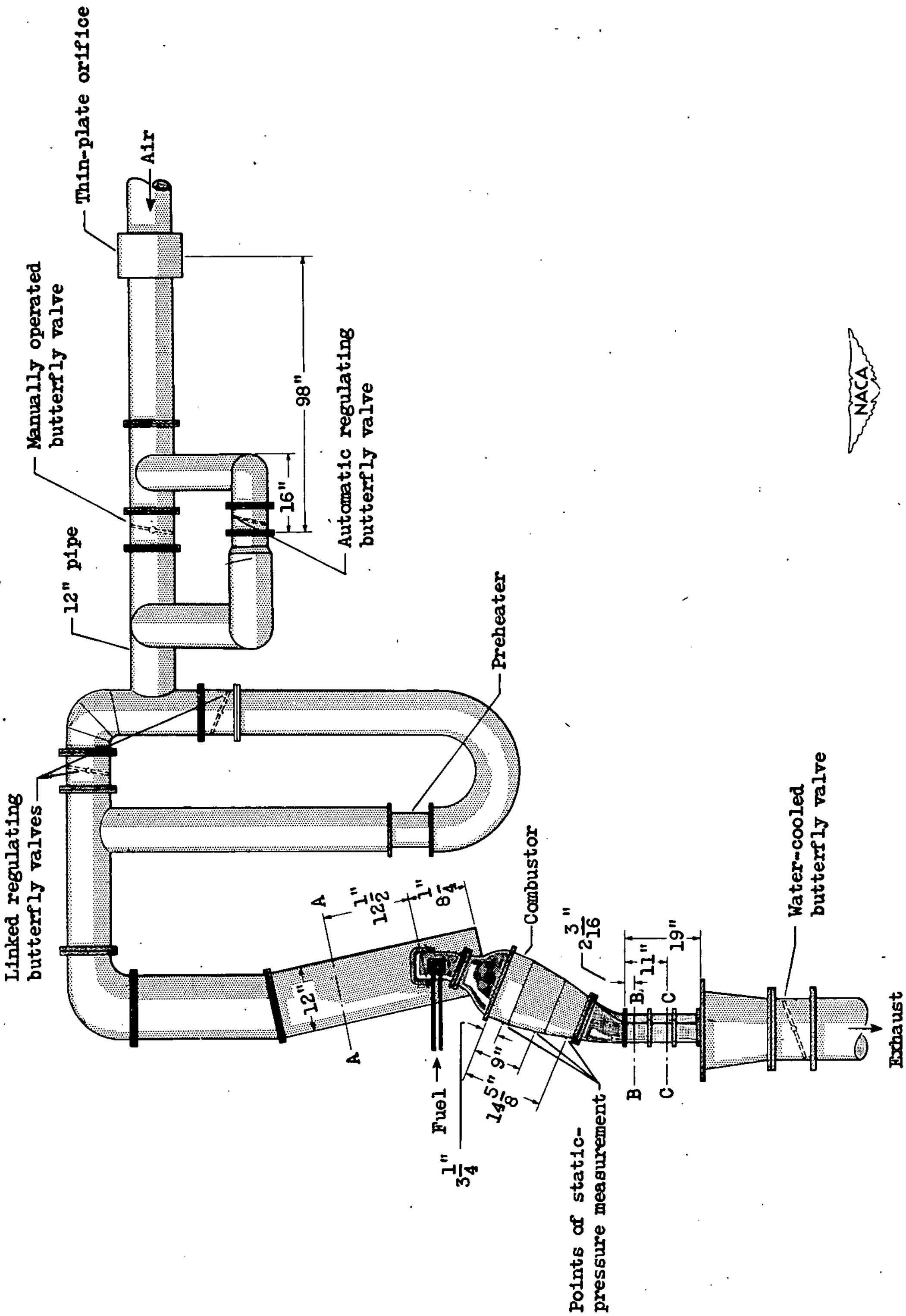
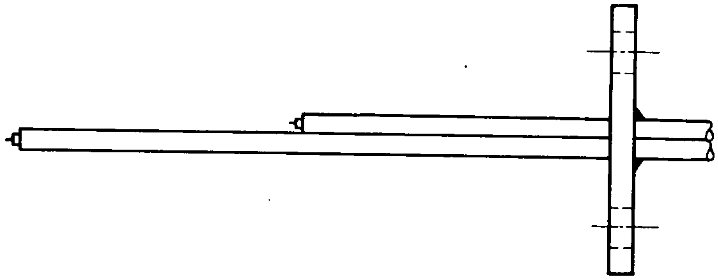
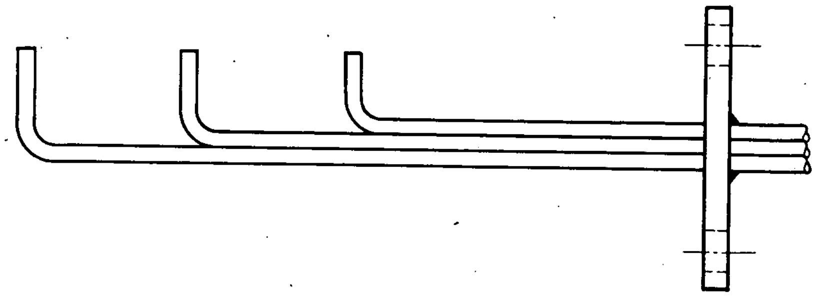


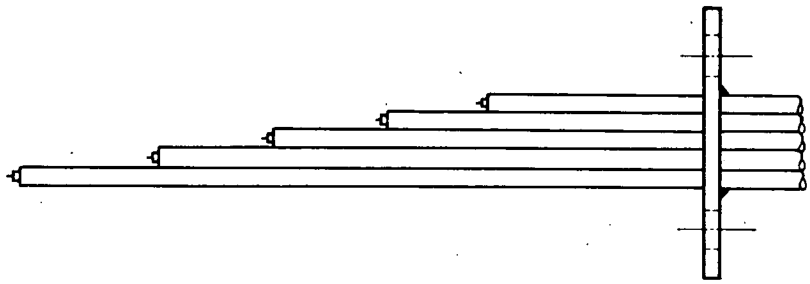
Figure 2. - Diagrammatic sketch of British-combustor setup.



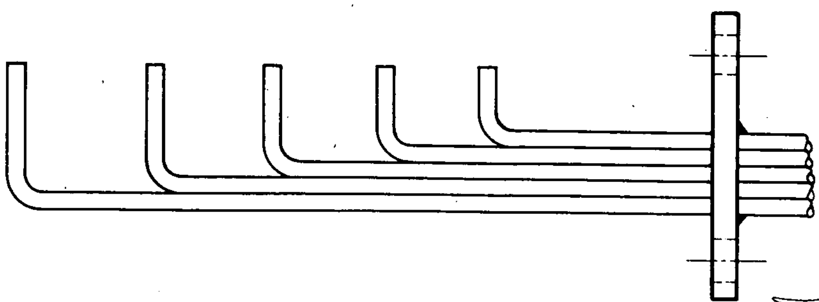
(a) Two-junction iron-constantan thermocouple rake.



(b) Three-tube total-pressure rake.



(c) Five-junction chromel-alumel thermocouple rake.



(d) Five-tube total-pressure rake.

Figure 3. - Instruments used for temperature and pressure measurements in British-combustor investigation.

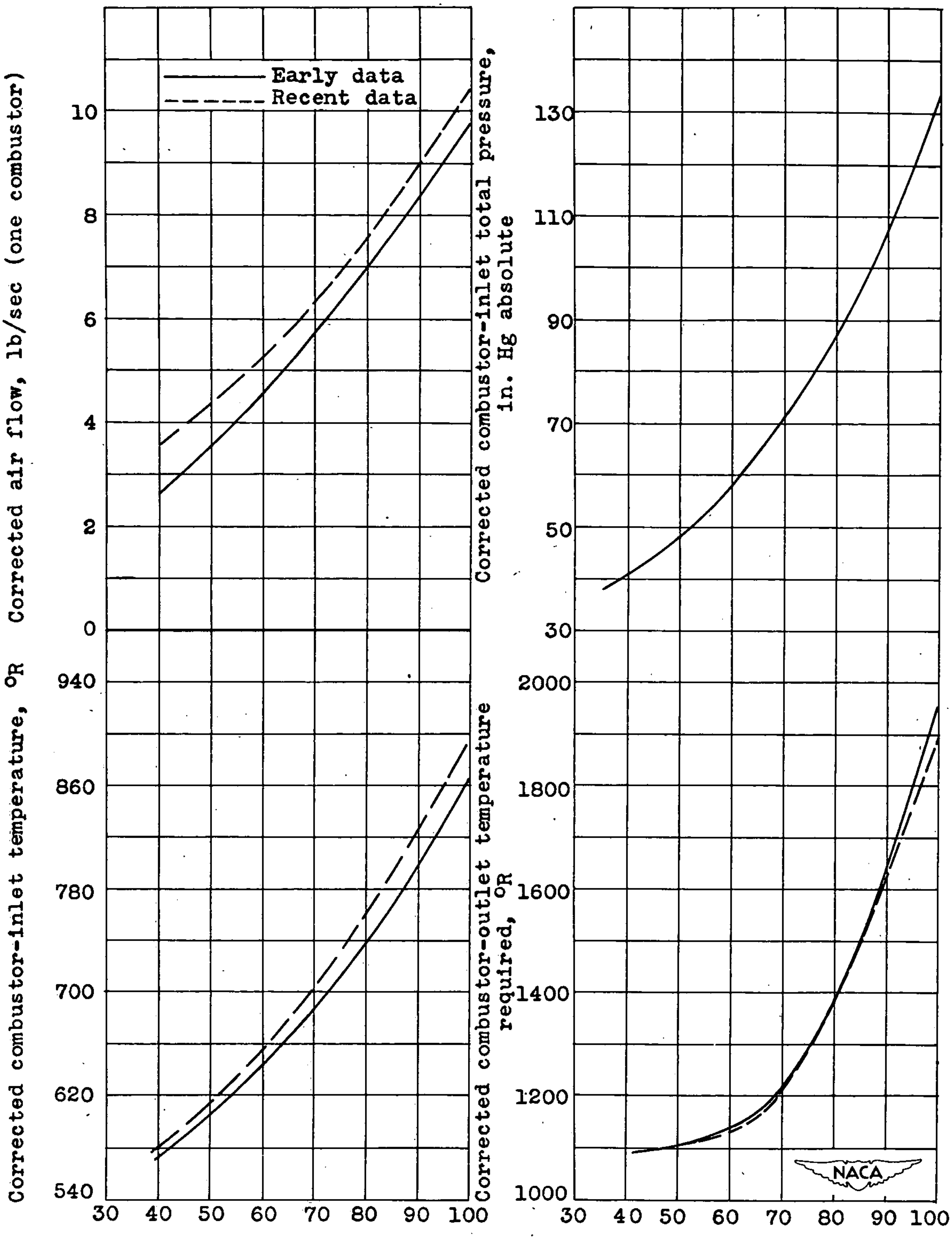


Figure 4. - British combustor experimental conditions. Performance data from engine runs.

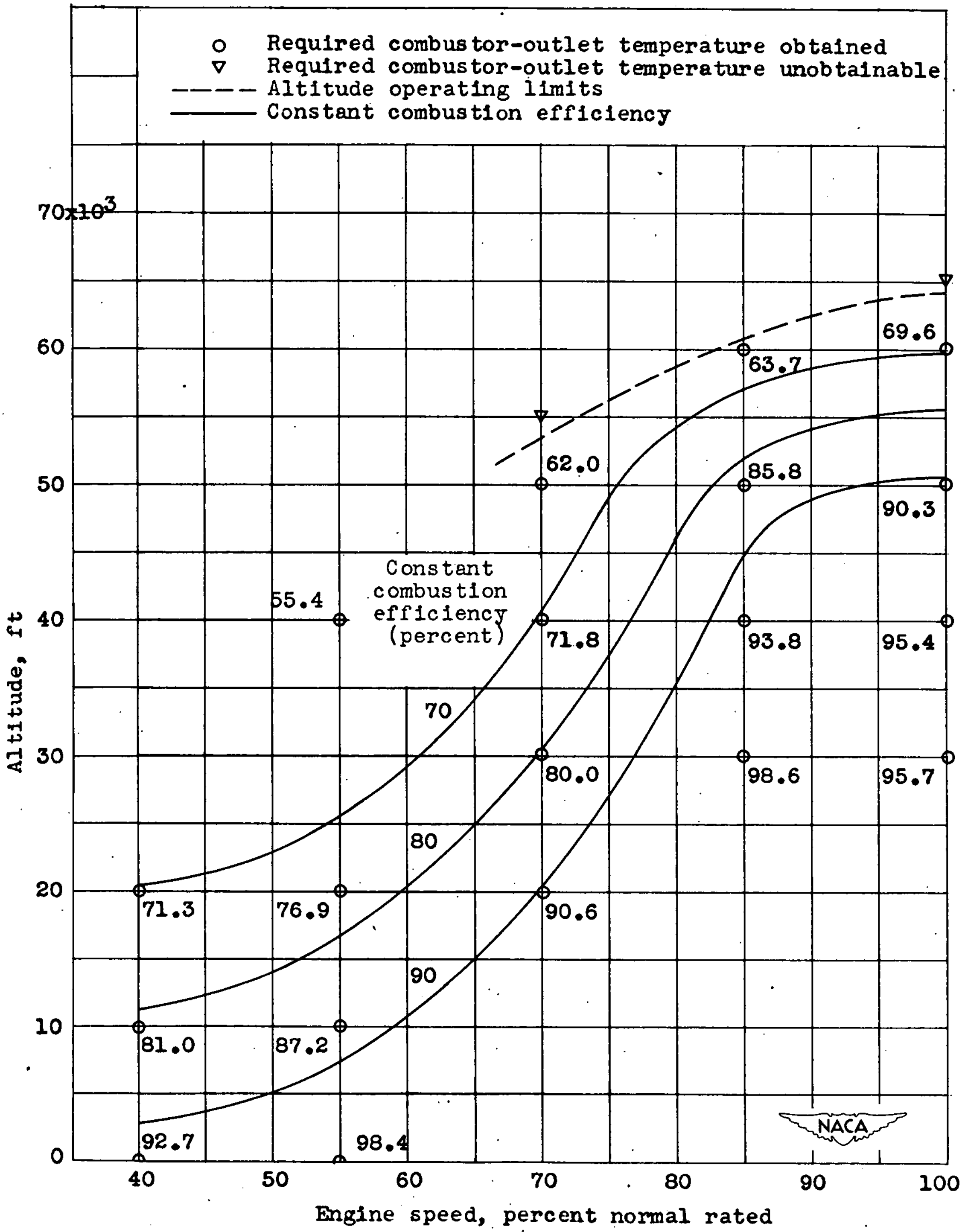


Figure 5. - Altitude operating limits and combustion efficiencies of British combustor. Fuel, AN-F-32; flight Mach number, 0. Values of combustion efficiency in percent are given beside data points.

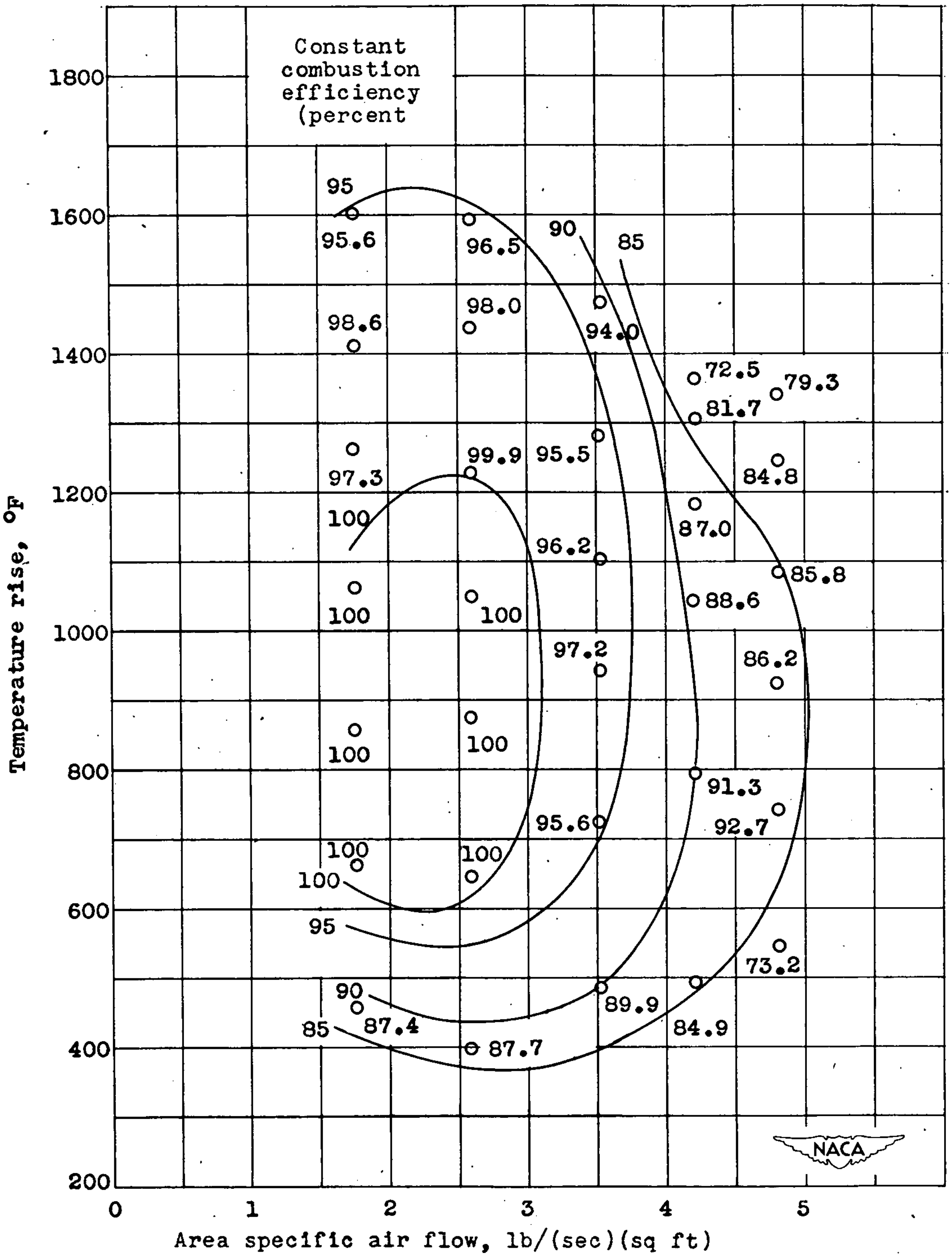


Figure 6. - Combustion efficiencies of British combustor at various air flows and values of temperature rise. Fuel, AN-F-32; inlet-air temperature, 620° R; inlet-air pressure, 15 pounds per square inch absolute; air flow based on cross-sectional area of housing. Values of combustion efficiency in percent are given beside data points.

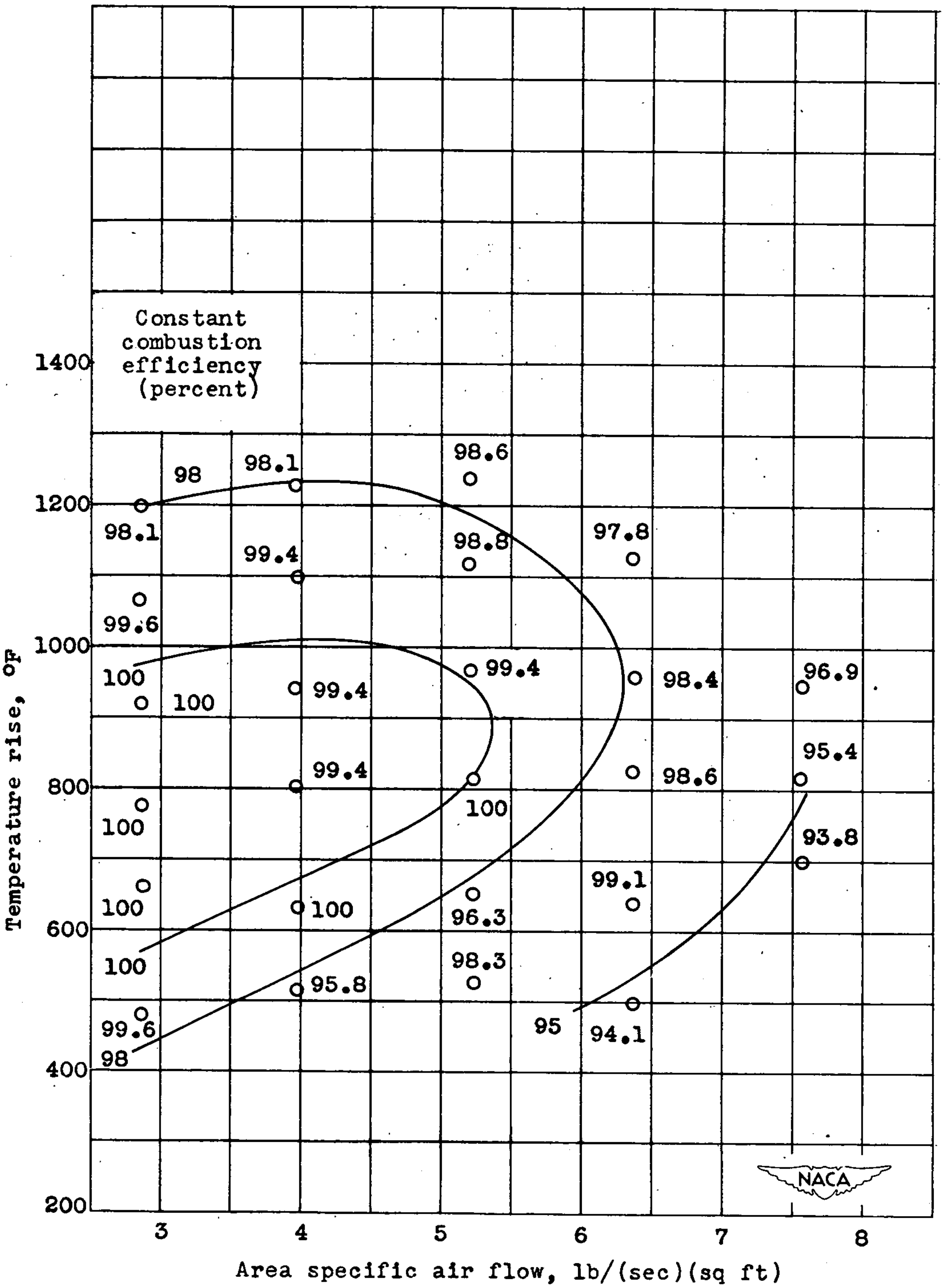


Figure 7. - Combustion efficiencies of British combustor at various air flows and values of temperature rise. Fuel, AN-F-32; inlet-air temperature, 710° R; inlet-air pressure, 25 pounds per square inch absolute; air flow based on maximum cross-sectional area of housing. Values of combustion efficiency in percent are given beside data points.

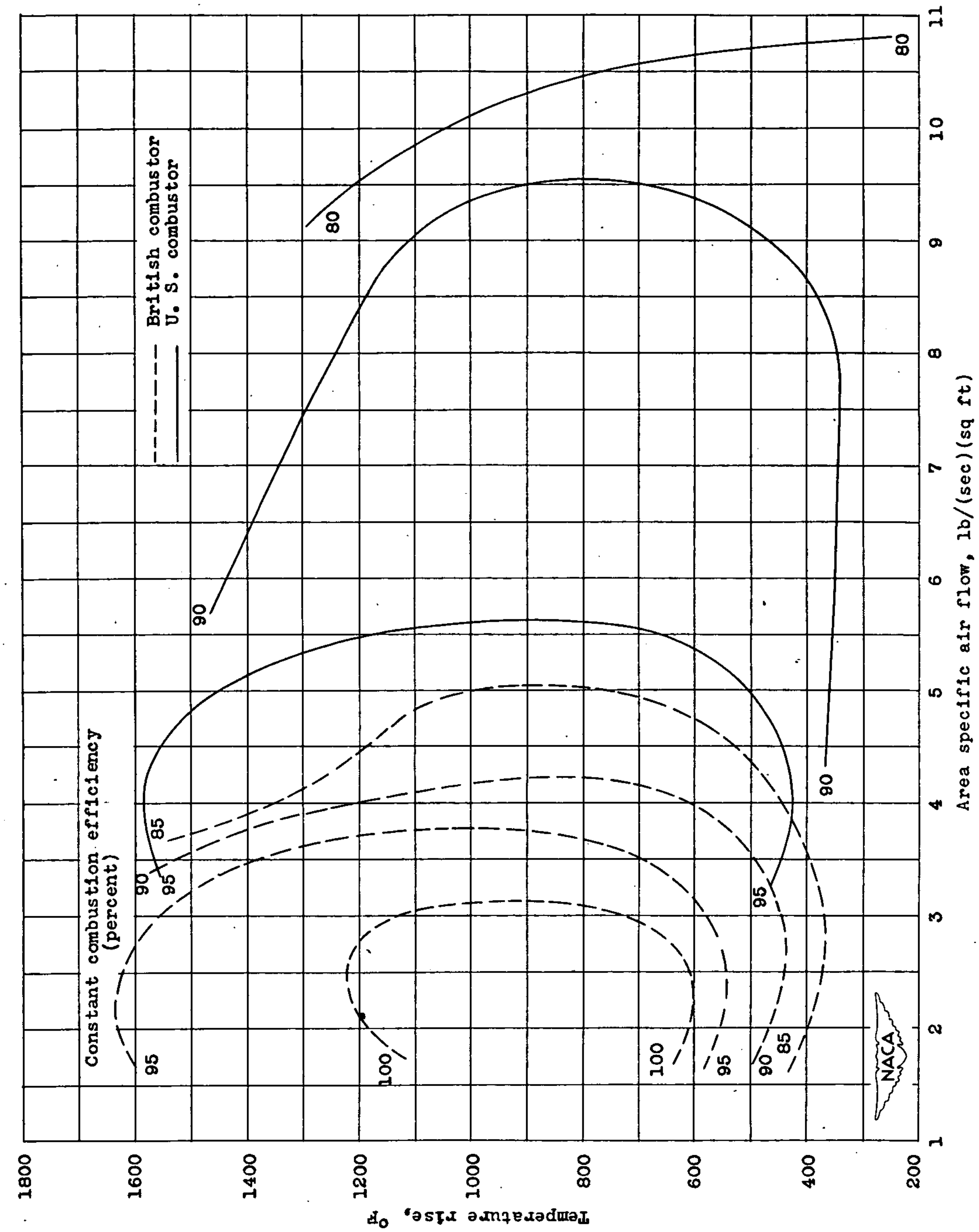


Figure 8. - Comparison efficiencies of British and U. S. combustors. Fuel, AN-F-32; inlet-air temperature, 620° R; inlet-air pressure, 15 pounds per square inch absolute; air flow based on maximum cross-sectional area of housing.

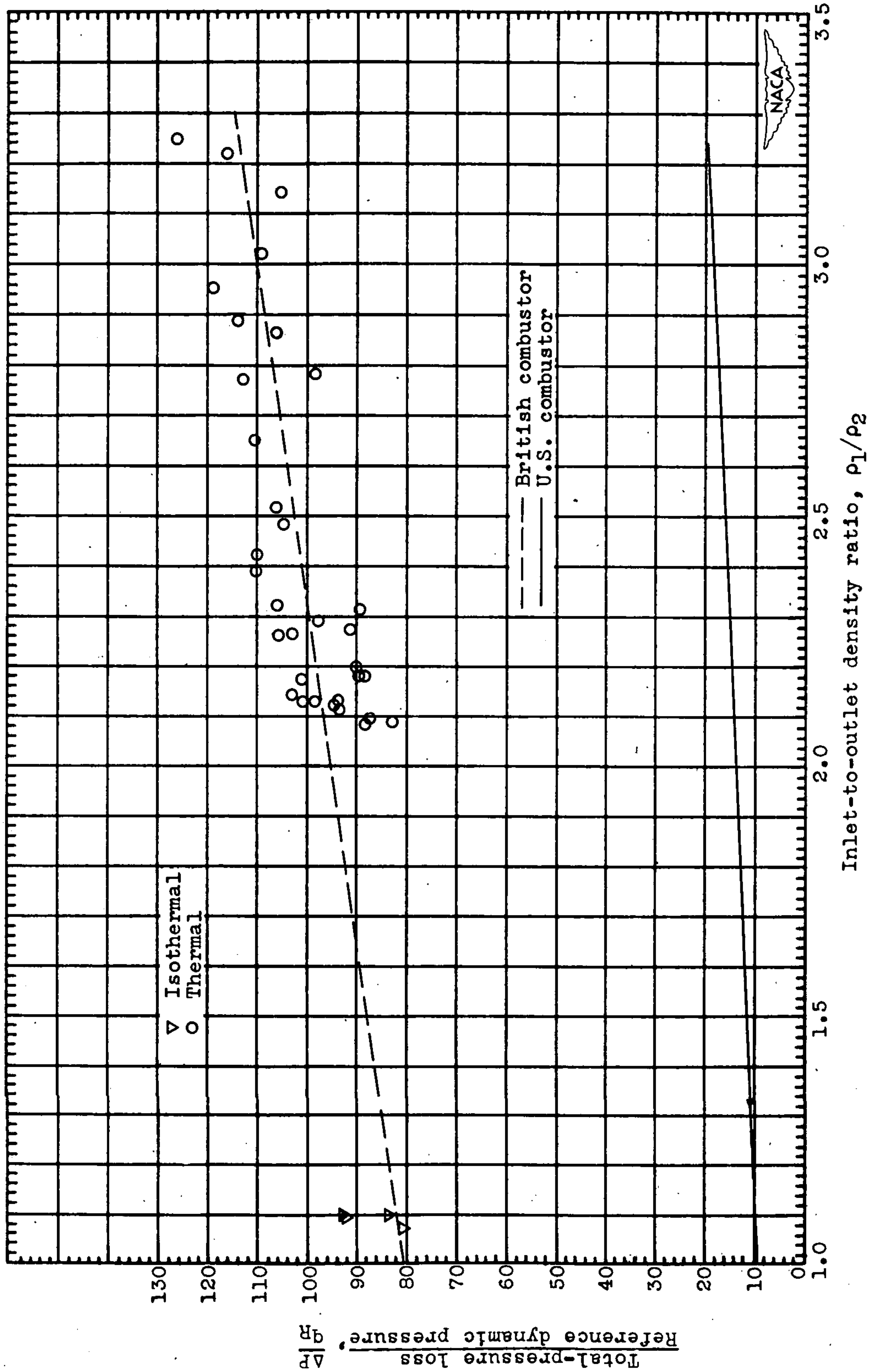


Figure 9. - Comparison of total-pressure losses of British and U.S. combustors.

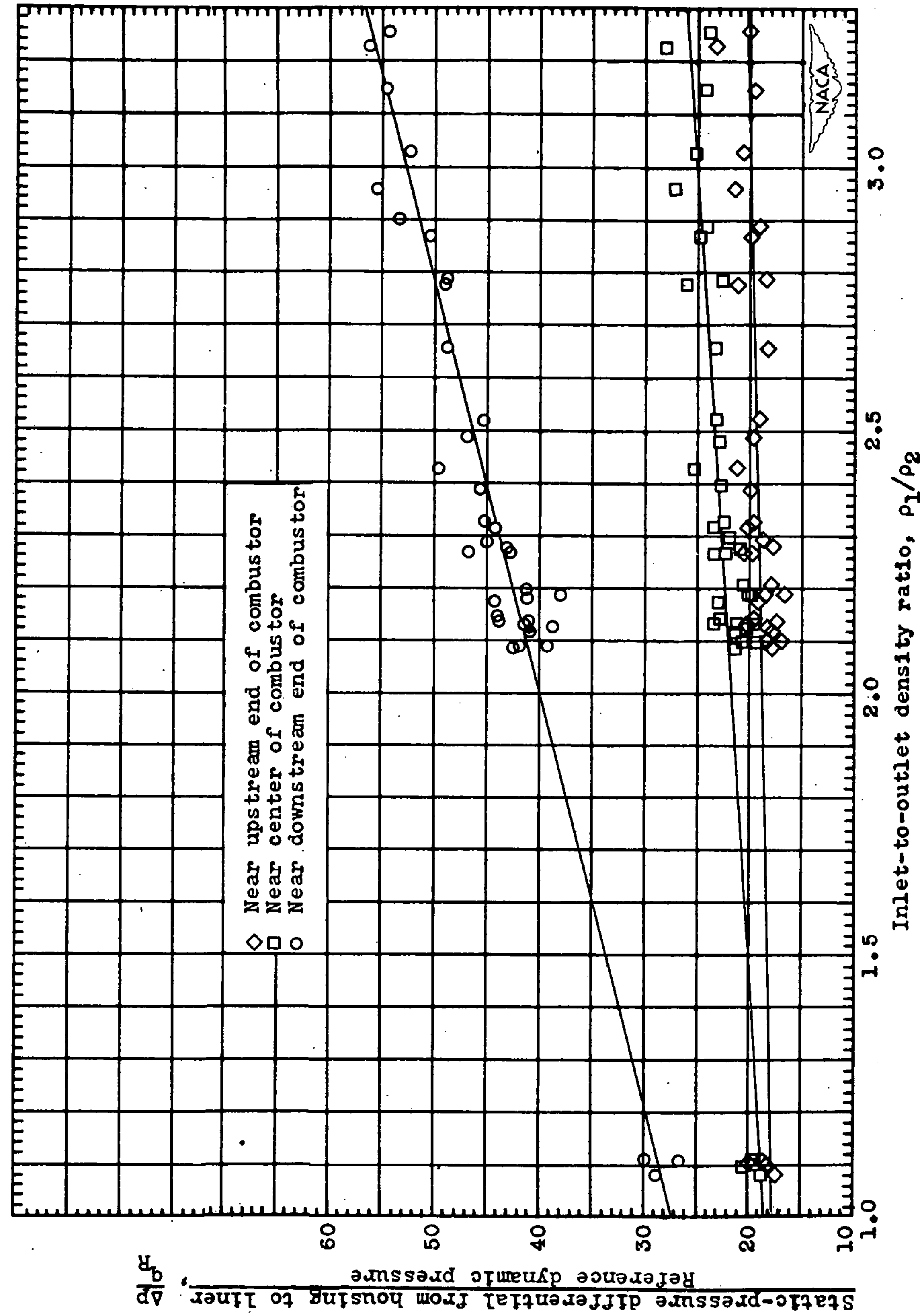


Figure 10. - Static-pressure differential from inside wall of housing to inside wall of liner of British combustor.

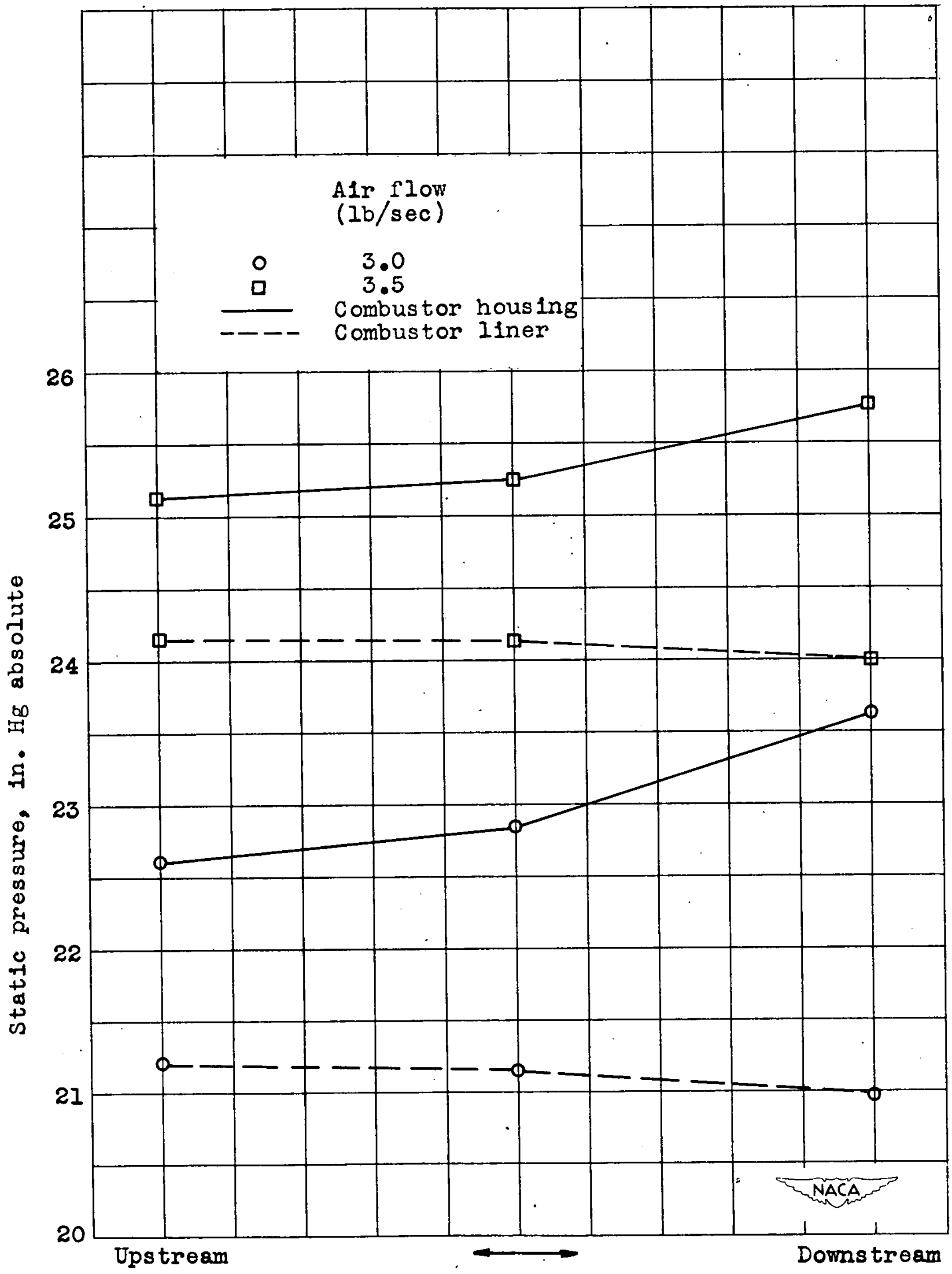
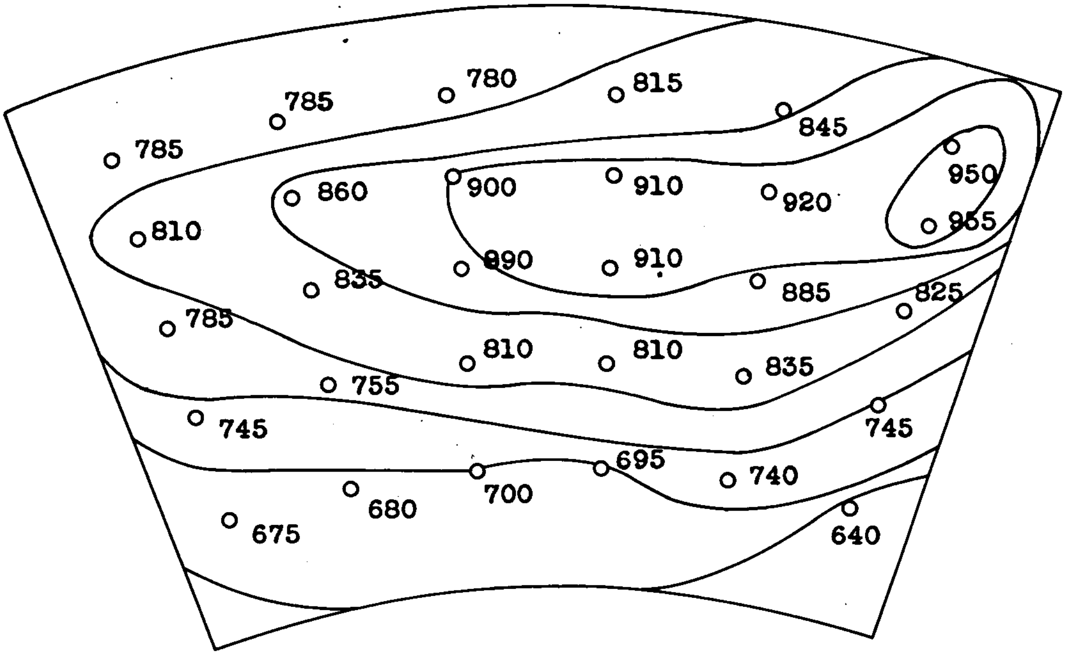
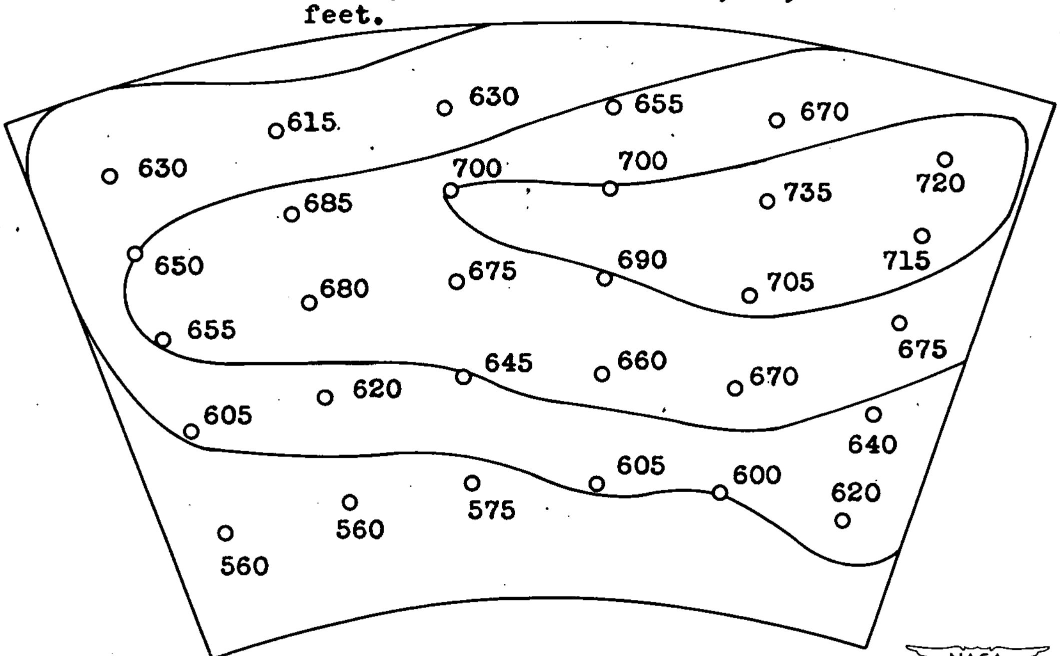


Figure 11. - Static pressures along inside walls of housing and liner of British combustor. Inlet-air temperature, 80° F; inlet-air pressure, 29.5 inches mercury absolute; fuel-air ratio, 0.

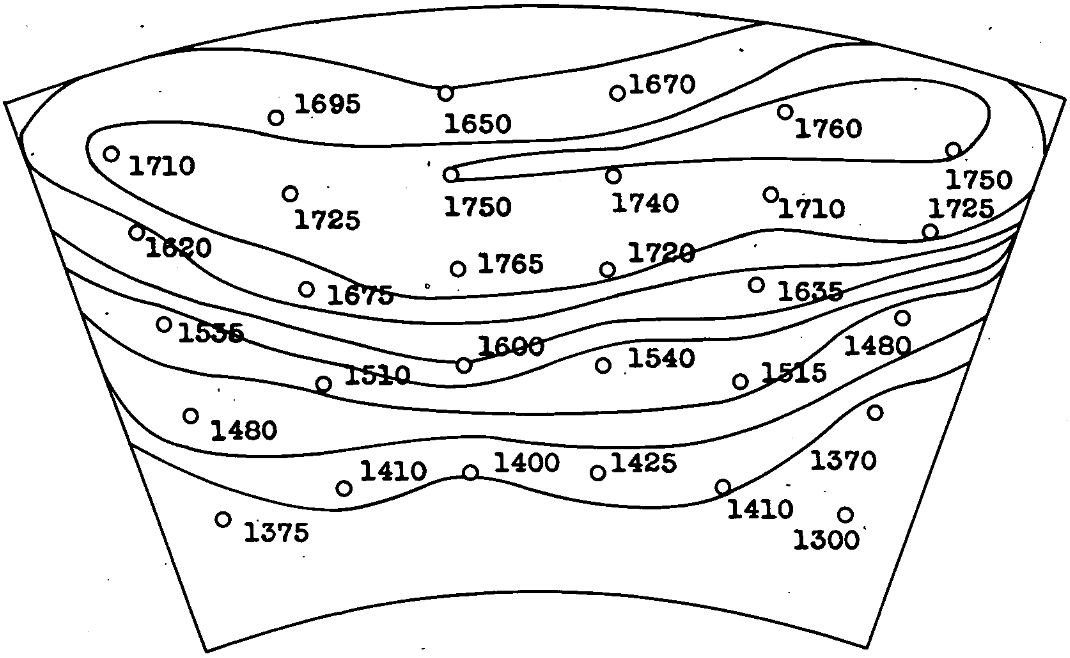


(a) Engine speed, 70 percent of normal rated; simulated altitude, 50,000 feet.

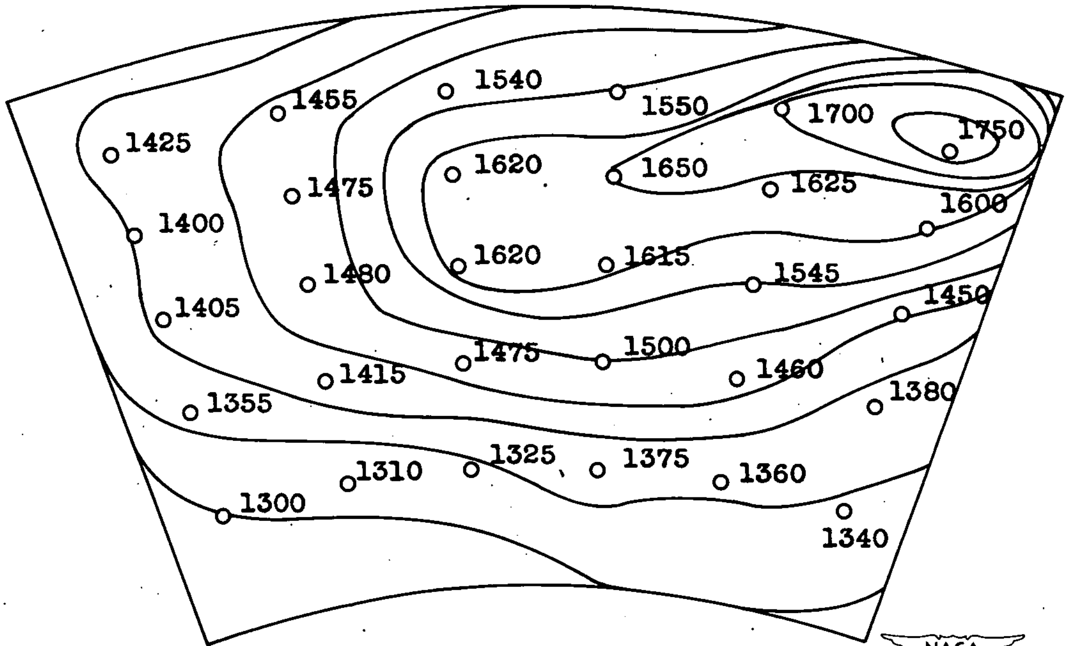


(b) Engine speed, 70 percent of normal rated; simulated altitude, 20,000 feet.

Figure 12. - Temperature-distribution pattern at instrument plane B in British combustor. Temperatures are given in °F.



(c) Engine speed, normal rated; simulated altitude, 60,000 feet.



(d) Engine speed, normal rated; simulated altitude, 30,000 feet.

Figure 12. - Concluded. Temperature-distribution pattern at instrument plane B in British combustor. Temperatures are given in °F.

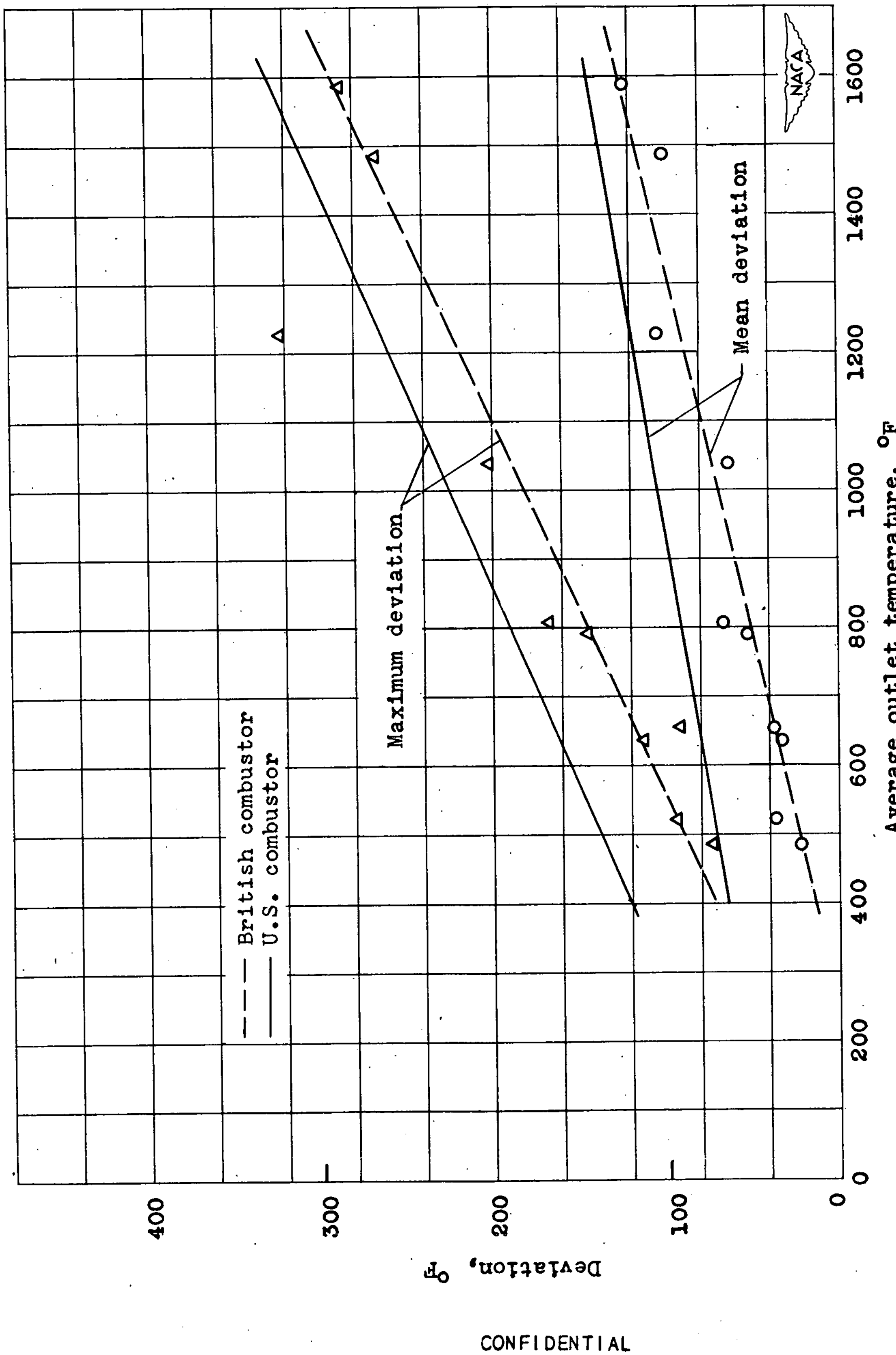


Figure 13. - Maximum and mean deviation from average outlet temperature of British and U. S. combustors.

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